Highlights of Astronomy, Volume 15
XXVIIth IAU General Assembly, August 2009
Ian F. Corbett, ed.

doi:10.1017/S1743921310010409

Special Session 1 - IR and Sub-mm Spectroscopy - a new tool for studying Stellar Evolution

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Preface

Infrared astronomy has come into its own over the last decade. Based on mature detector technology and sophisticated instrumentation it is contributing exciting science in many fields of astrophysics. Stellar evolution is a field that has long been dominated by ultraviolet and optical work, but one that has benefited from a strongly increasing contribution from the infrared (IR) and sub-millimeter (sub-mm) domains. In particular, spectroscopy in these domains holds the promise to enable important advances through quantitative analysis of individual stars and stellar systems.

All facets of stellar evolution, from star formation to advanced stages of stellar evolution will be impacted by the higher sensitivity and fidelity of the new astronomical spectral observations. Infrared and sub-mm observations, in particular, are needed for accurate quantitative analysis of: proto-stars and the formation of multiple star systems, formation of proto-planetary and debris disks, massive star properties and winds, stellar outer envelopes for mass loss in AGB stars, velocity fields for mass outflows and jets from young stars and eruptive variables, tests of stellar nucleosynthesis using post-main sequence stars, chemical composition studies for cool stars, cold gas, and high excitation, low density plasmas, stellar magnetic fields from magnetically sensitive IR spectral lines, and chemistry and kinematics of red giants and supergiants in metal-rich stellar clusters and galaxy fields.

The progress to be made in astrophysics is linked to advances in technology. In the recent past there have been at least three obvious advances in instrumental capabilities:

- a tremendous gain in sensitivity, be it the follow up of first-generation spacecraft (*IRAS* and *ISO*) by today's *Spitzer Space Telescope* or *WISE* or when comparing the first-generation single-detector CVF photometers at seeing limited 2 to 4 m class telescopes with multi-mode instruments or diffraction limited 8 to 10 m telescopes with $(2k)^2$-detectors being considered state-of-the-art,
- a gain in resolving power over the IRAS resolving power of $\frac{\lambda}{\Delta\lambda} \approx 20$. At the onset it was barely possible to discriminate solid-state features from atomic emission lines. Adequate spectral resolution was only achieved with Fourier transform spectrometers or heterodyne receivers, albeit with extremely low sensitivity. Only recently have sensitive spectrographs become available, allowing for meaningful single-line absorption spectroscopy in stellar atmospheres,
- and adaptive optics, which has allowed for diffraction limited spectroscopy relevant to investigating the circumstellar environment, is now readily available. More sophisticated techniques, such as interferometry or spectro-astrometry, routinely provide for spectroscopic information on milli-arcsec scales.

At this point, the rapid evolution in IR spectroscopy, mostly based on detector technology, has subsided and substantially larger telescopes are needed. Detailed trade-offs are required from first-generation instrumentation as to how to use the detector pixel real-estate: echelle cross-dispersion versus single-order integral-field spectroscopy. It appears that for stellar evolution spectral coverage (cross dispersion) is more important than the integral field. However, an even more basic concern is that first-generation instrumentation on Extremely Large Telescopes (ELTs) may not include spectrographs capable of resolving stellar lines. Unfortunately, no IR multi-object fiber-fed spectrographs are on the horizon, even though this concept has been proven invaluable in optical spectroscopy. In addition, although spectropolarimetry in the IR offers fundamentally better performance (higher contrast and weaker fields possible), this technique has unfortunately not yet been implemented anywhere.

An optimistic outlook on IR and sub-mm spectroscopy is justified by several developments coming together at this point in time, which will effectively turn it into a new tool that is considerably more potent than the sum of its parts.

• Evolution of technology relevant to IR and sub-mm spectroscopy is continuing to advance, resulting in evermore powerful combinations of instruments and detectors. The *Spitzer* and AKARI IR space observatories and modern high-resolution spectrographs (Phoenix, CRIRES, VISIR, TEXES) operating in the 1 to 25 micrometer region are cases in point. In the near term several large dedicated facilities on the ground (ALMA), at high altitudes (SOFIA), and in space (*Herschel Space Telescope*) will become available, which will significantly enhance the observational capabilities in terms of spatial and spectral resolution, sensitivity and access to wavelength domains.

• Large IR surveys, such as UKIDSS and the *Spitzer* Legacy Programs, or the upcoming VISTA surveys, produce extensive public data sets that can be mined for intriguing objects and follow-up observations with state-of-the-art instrumentation. For example, large IR surveys (e.g., Gould Belt) are now providing complete samples of young stellar objects in clouds down to the planetary mass regime, allowing time scales for different evolutionary phases and processes of clustered versus non-clustered star formation to be tested.

• The IR spectral range accessible today spans some four octaves; therefore, advances in calibration techniques are necessary to remove the need to rely on a single method, e.g. atmospheric features, for frequency calibration. With the vast development of sensitive high-dispersion grating spectrographs the issue of frequency calibration in IR spectroscopy became relevant. The calibration standards available today, telluric atmosphere hollow cathode lamps characterized in the IR and the NIST legacy, connecting a broad selection of molecular transitions to be used in gas-cells to the time standard, have paved a very convenient way. More sophisticated methods, etalons and frequency combs, are on the horizon, ensuring that frequency calibration never will be a limiting factor in spectrum analysis. Indeed, absolute precision traceable to the time standard will soon become the norm.

• The advances in stellar modeling have also helped to establish spectrophotometric standard stars. While in the near-IR one can select true standard stars, such as white dwarfs, in the thermal-IR regime compromises must be made due to the reduced instrument sensitivity. Good general modeling of SEDs and detailed spectra for atomic lines are now available.

• Excellent facilities in laboratory astrophysics are starting to make significant progress in establishing the fundamental data necessary to provide the required ground truth for the IR domain, covering many aspects of atomic, molecular and solid state physics. Calibration sources (discharge lamps and gas cells) traceable to laboratory standards are becoming available for the IR. These advances in calibration techniques are changing the paradigm for wavelength calibration to an approach similar to the ultraviolet-optical domain. Still, the Earth's atmosphere will remain a valuable tool for wavelength calibration in some spectral regions.

• Sophisticated modelling of stellar atmospheres and the theory of stellar evolution is providing a more complete picture with which the growing mosaic of observations and measurements can be compared. State-of-the-art database infrastructure is making all such data easily accessible on an unprecedented scale.

• As has been demonstrated at this conference, and elsewhere in the literature, the HITRAN data base combined with a line-by-line radiative transfer code now also allows the removal of effects from telluric absorption to a high level of precision, e.g. by employing a realistic treatment of pressure broadening in combination with true atmospheric profiles available from meteorological databases. Only occasional telluric standard star observations are required, hence the efficiency of ground-based spectroscopy benefits fundamentally, an important issues when it comes to ELTs, where observing time will be very expensive.

• Finally, progress is being made towards better characterizing the properties of the Earth's atmosphere and its impact on astronomical observations. Active real-time correction of seeing through adaptive optics (AO) facilities, also involving laser guide stars, will become routine operations. Especially in the era of ELTs, source confusion will be a real problem. Only AO-assisted spectroscopy will allow unambiguous studies of stellar populations beyond the closest members of the local group. This is only possible in the near-IR and thus, to prepare ELT programs for near-IR stellar spectroscopy is of paramount importance. Measurement of the water vapour content of the atmosphere above an observatory is about to become a routine practice. A stand-alone monitor of precipitable water vapour allows to assess the quality of a given night and will greatly facilitate the scheduling of IR observations in service mode.

It was our aim that this General Assembly Special Session foster collaboration between various fields, bringing together experts from theoretical and observational astrophysics, instrumentation and laboratory spectroscopy to develop an integrated approach to applying IR and sub-mm spectroscopy to the study of stellar evolution. In combination, these fields hold the key for the scientific success of the current and planned facilities. New observations will foster new thinking about old problems, reveal unexpected phenomena and lead to transformative thinking. This conference occurred at a particularly advantageous time for transferring knowledge in IR and sub-mm spectroscopy from mission to mission. Certain space missions have produced a wealth of data; *Spitzer Space Telescope* completed its cryogenic mission and entered the “warm” phase, while AKARI had ended operations after completing an all-sky survey. Others are either undergoing their on-orbit commissioning phase (*Herschel Space Telescope*) or are making advanced preparations (SOFIA). New ground-based facilities have matured to be able to present results of unprecedented quality.

This symposium engaged the laboratory data producers and users in fruitful discussions that educated the astronomers on the limitations of available data and lead to new collaborations and projects for laboratory investigations and calculations for basic data that are necessary to perform reliable quantitative analyses of the new astronomical spectra. From the perspective of atomic and molecular spectroscopy the advances in astronomical instrumentation at IR and sub-mm wavelengths poses many challenges. Despite the fact that IR spectroscopy has been an active research field for decades, the advent of recent, relatively high-resolution astronomical spectroscopy reveals stark deficiencies in the completeness and accuracy of the atomic, molecular, and solid-state data needed for both the simple tasks of line identification and chemical abundance analysis and more complex tasks of modeling stars and their environments. It is sometimes overlooked that molecular spectroscopy in the radio/sub-mm regime and near-IR spectroscopy observe the same molecules, with the only difference being that radio lines are nearly always pure rotational transitions, while IR transitions also change their vibrational state. Still, protagonists of these two world-views do not often enough make sensitivity calculations for the respective other technology, even though the cross-fertilization might be fundamental. We hope this workshop has helped to combine the two communities, so that ALMA and the 8 to 40 m class telescopes will be utilized in a coherent way.

The broad interest in this Special Session was attested to by the support from a number of Commissions (14, 34, 36, 44, 45) and Working Groups (Red Giants), in additon to the sponsoring Commission 29, representing four IAU Divisions. The conference was well attended at all sessions, and fostered lively discussions. The oral presentations were complemented by poster papers, which are listed at the end of the table of contents. The written contributions presented in *Highlights* for this Special Session are meant to convey the nature of the oral presentations, all of which were of high quality. The speakers were charged with presenting the broader picture in their subjects so that after a few days the attendees could synthesize the status of IR spectroscopy. It was clear that all aspects of stellar astronomy and its supporting technologies are still finding their way in this era of increased activity at IR and sub-mm wavelengths, which makes for an exciting time of rapid discovery and awareness.

It is a great pleasure to acknowledge the contributions of the remainder of the Organizing Committee (France Allard, Thomas Ayres, Steven Federman, Carol Grady, Bengt Gustafsson, Kenneth Hinkle, Chiyoe Koike, John Lattanzio, Gillian Nave, Livia Origlia, Peter Schilke, Jonathan Tennyson, Stepan Urban, and Ewine van Dishoeck) for their role in creating the scientific program. We would also like to thank the IAU for extending financial support to a number of our attendees, Session Chairpersons, and the Brazilian LOC for accomodating all of our needs.

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Garching bei München, December 1, 2009

https://doi.org/10.1017/S1743921310010409 Published online by Cambridge University Press